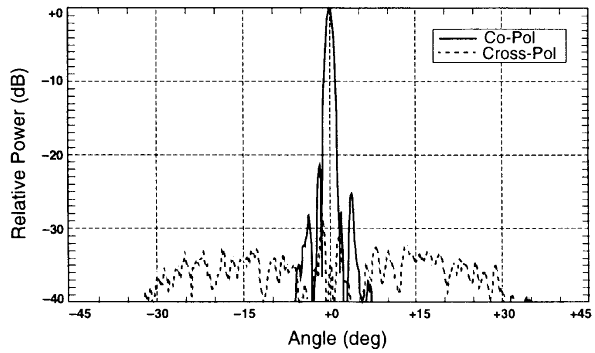
FIGURE 2. MEASURED RADIATION PATTERN OF THE REFLECTARRAY AT 32 GHz.



that were designed to resonate at 32.0 GHz. Each patch, with a square dimension of 2.946 mm, has two transmission phase delay lines orthogonally attached with one longer than the other by 90°. Each patch has a unique rotation angle, depending on the phase required to achieve the far-field beam coherence. All patches are etched on a 0.254-mm-thick Duroid substrate having a relative dielectric constant of 2.2. The reflectarray has an f/D ratio of 0.75. The etching tolerance achieved across the aperture for the patches is ±0.008 mm. A great deal of effort was spent in assuring the achievement of this tolerance for this breadboard unit. It is believed, once the production process is set up, that the manufacturing effort for achieving the required tolerance can be significantly relaxed. To ensure a flat reflecting surface, the thin Duroid substrate is supported by a 1.9-cm-thick aluminum honeycomb panel. The feed, a corrugated conical horn, is precision fastened above the honeycomb panel by four aluminum rods of 1 cm diameter. The overall antenna mass is 1.65 kg. It is estimated that, with additional effort, the antenna mass can be reduced to 1kg or less.

The radiation pattern of the microstrip reflectarray measured at 32.0 GHz is shown in Figure 2. It has a peak sidelobe of -22 dB, and all other sidelobes, except the first few, are well below -40 dB. The first two high sidelobes are believed to be caused by the feed blockage. All the cross-pol radiations, except one cross-pol lobe at –28 dB level, are well below -30 dB. Besides good design and precision fabrication, one major reason for the achievement of low sidelobe and cross-pol levels is the diffused, instead of coherent, scatterings by the randomly rotated patches. Although rotations of all patches have a unique pattern for the co-pol field; they appear to be randomly rotated to the patch-scattered component field and the cross-pol field. The antenna has a -3 dB beamwidth of 1.2° and a peak gain of 42.2 dB at 31.7 GHz. This gain corresponds to an overall antenna efficiency of 60 percent which is considered quite good for an array antenna at a Ka-band frequency with a large number of elements. The bandwidth behavior of this antenna is shown in Figure 3 where the antenna gain and efficiency are plotted against a frequency in the range of 31 GHz to 33 GHz. The –1 dB gain bandwidth is 1.1 GHz which is about 3.5 percent. This bandwidth is quite adequate for telecommunication applications at Ka-band. Wider bandwidth can be achieved by redesigning the patch element and by using time-delay lines instead of the phase-delay lines used here.

Applications

As discussed at the beginning, the printed reflectarray combines the best features of the parabolic reflector and the microstrip reflectarray. These features contribute to its many potential applications [5] :

- This antenna will have extreme low mass when conformally mounted to a spacecraft.
- The antenna can be integrated with the solar array when

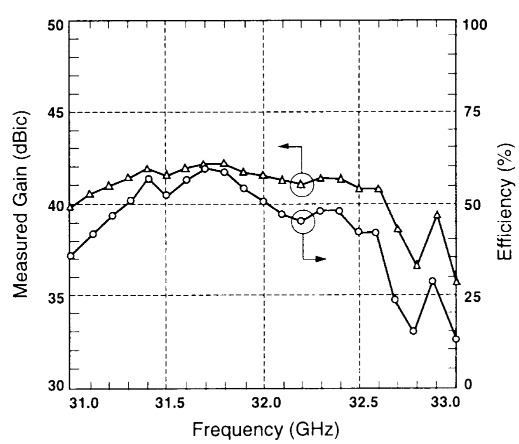


FIGURE 3. MEASURED REFLECTARRAY ANTENNA GAIN AND EFFICIENCY VS. FREQUENCY. IT SHOWS A 1 dB GAIN BANDWIDTH OF 1.1 GHz.

CONTINUED ON PAGE 11

RADIO SCIENCE RESEARCH

THROUGH THE SOLAR WIND: THE DSN MEASURES ELECTRON DENSITY OUTSIDE THE ECLIPTIC PLANE

SAMI ASMAR

In addition to performing communication functions for space missions, the Deep Space Network (DSN) is a world-class instrument for Radio Science research. Scientists use the receiving and tracking equipment, as well as the more specialized Radio Science equipment and associated media calibration instrumentation, to measure very small changes in the phase, amplitude, and other characteristics of spacecraft radio signals. These measurements allow the investigation of various phenomena in the solar system, including the structure of the atmospheres of the planets and their satellites, the masses and gravitational fields of the planets and their satellites, and verifications of aspects of the theory of general relativity. Another important Radio Science investigation is the atmosphere of the star that directly affects our lives on earth; the Sun. The solar corona (close atmosphere) and the solar wind (extended atmosphere) have been sounded via radio signals transmitted by the Ulysses spacecraft during a three-week interval of its superior conjunction in the winter of 1995. This is an experiment configuration where the spacecraft is behind the solar corona, as viewed from earth, and its transmitted radio signals travel through the corona prior to reception at the ground stations. Because its index of refraction is higher than free space, the corona causes a small delay of the signal. The delay can be measured because of the highly accurate clocks at the DSN stations (called frequency and timing reference masers). Ulysses was not the first spacecraft to perform a coronal occultation experiment, but was the first to be on a trajectory taking it from the South pole to the North pole of the Sun, breaking the restriction of all previous experiments to be near the

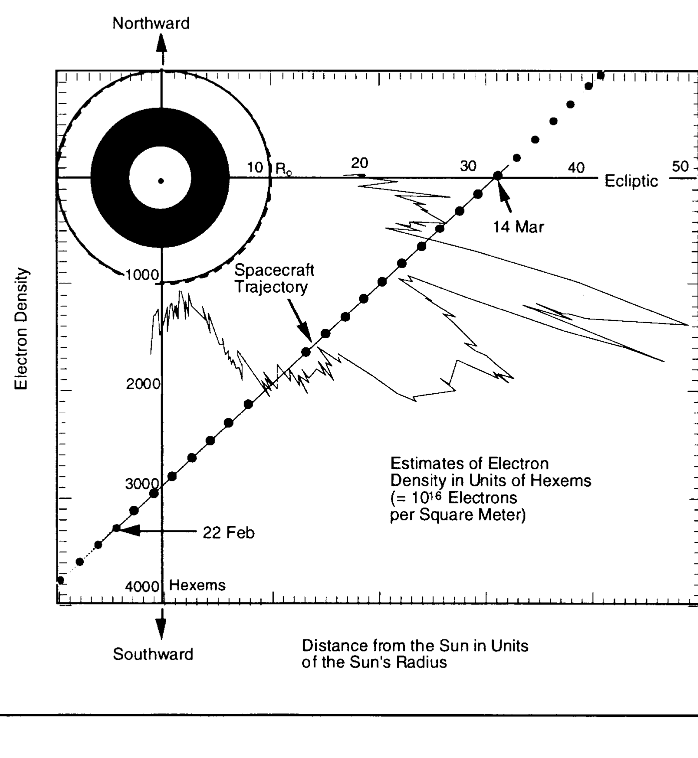


FIGURE 1. SOLAR DISK VIEW OF ULYSSES 1995 CONJUNCTION (NOT TO SCALE)

SOLAR WIND CONTINUED FROM PAGE 9

ecliptic plane. Figure 1 illustrates this path of flight as viewed from Earth, marked in distances of solar radii, with a grayscale image of the corona from March 8, 1995, magnified by a factor of three, placed at the position of the Sun. The figure also shows a pictorial summary of the observations, namely the electron content at each position along the trajectory using units of hexems (ten to the sixteenth power of electrons per square meter). The high inclination orbit, as well as the availability of two radio signals (one at 2.9 GHz and the second at 8.4 GHz), allowed for measurements at a solar ray path offset of a tenth of an astronomical unit.

Dr. Mike Bird, the Principal Investigator from Bonn University, reported that the density of electrons along the line-of-sight column between Ulysses and Earth clearly shows the signature of the polar coronal hole (a region of very low electron concentration) and a streamer belt (area of coronal mass being ejected) at low altitudes. Team member Dr. Martin Paetzold reported that an increase in electron content by a factor of two is recorded from the center of the southern pole coronal hole to the Equator. A streamer belt, identified by an abrupt rise in electron content, rotated into the ray path at southern heliographic latitudes between 16 and 21 degrees.

These observations are used to test models of the heliographic latitude dependence of the electron density in the inner heliosphere. Traditional models for solar activity minimum, whereby the density decreases slowly from equator to pole, were found to fare poorly in representing the measurements. In contrast, a model based on Ulysses in situ solar wind measurements was found to provide satisfactory agreement with the radio sounding data.

The Deep Space Network enabled this experiment by providing the capability for ranging measurements. A digital code that is modulated onto the signal transmitted from the ground station is then received by the spacecraft and retransmitted back to the ground station. The round-trip time of the coded signal traveling at the speed of light is then measured with high precision. When two signals at two frequencies (or wavelengths) travel simultaneously through the solar wind, they experience different time delays, and the measurement of the difference in the time delays (referred to as differential ranging) provides a powerful scientific tool leading to these important results.

SURFSAT-I CONTINUED FROM PAGE 6

and predict generation, for Space VLBI station tests, and for Ka-band antenna pointing system performance. The Ka-band antenna pointing and auto-tracking systems tested were (1) conscan, (2) monopulse, and (3) the seven-element feed array.

The SURFSAT project owes thanks to Utah State University and the Globesat Corporation personnel (Logan, Utah) for guidance given during the two-week course. In all, since 1987, more than 60 students from 14 colleges in the United States and United Kingdom have participated in the design and construction of SURFSAT-1. The students received help from many Jet Propulsion Laboratory engineers and technicians during the nine-year development project. Contributions to SURFSAT's success were made by engineers in many different organizations, including the National Aeronautics and Space Administration's Launch Vehicles Office, Goddard Space Flight Center's Orbital Launch Services Project, McDonnell Douglas Aerospace, Phillips Lab at Edwards Air Force Base, Neo-Comm Systems Incorporated in La Crescenta, Applied Solar Energy Corporation (now called TechStar), and TRW.

SURFSAT has met its educational outreach and technological goals, and also succeeded in meeting several new requirements for tests of DSN equipment and systems.

KA-BAND CONTINUED FROM PAGE 8

printed dipole elements, rather than patches, are used in the reflectarray.

- Due to its flat reflecting surface, for large aperture applications, the antenna can more easily accommodate an inflatable or foldable configuration.
- Because of its low sidelobe and low cross-pol radiations, the antenna can achieve high-beam efficiency for radiometric application.
- It can be used as a "phased reflectarray" for wide-angle beam scanning application by incorporating phase shifters or micromachined motors.
- The antenna can be mounted on the side wall of a building or the rooftop of an automobile for commercial DBS application.

Conclusion

An innovative microstrip reflectarray antenna has been successfully developed at a Ka-band frequency for possible future small spacecraft application. It has several significant advantages over the conventional parabolic dishes. The many potential applications of this antenna warrant its further development.

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